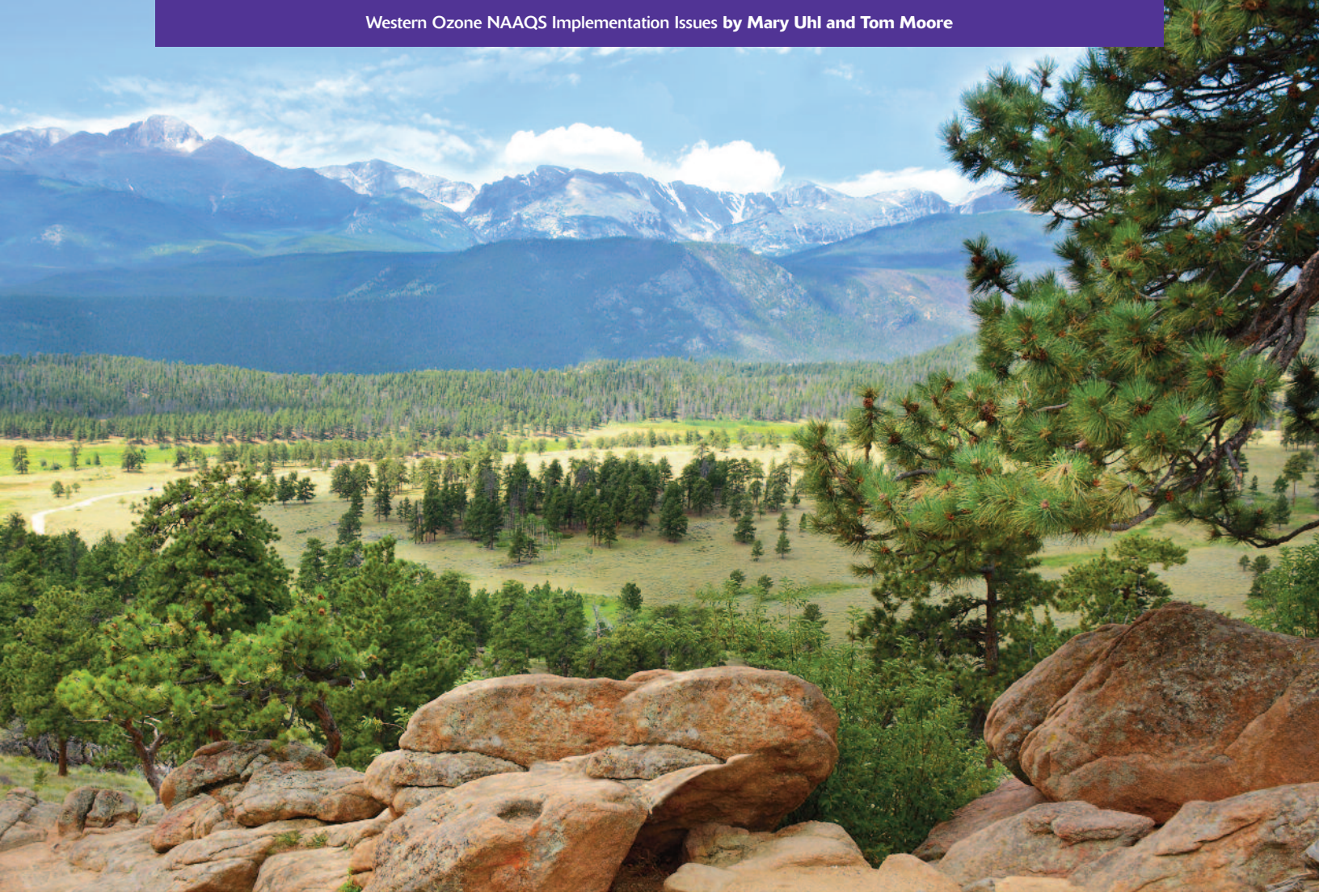

Western Ozone NAAQS Implementation Issues:

Addressing Background and Transport

As the National Ambient Air Quality Standards (NAAQS) for ozone (O_3) have changed in form and stringency over the past two decades in order to protect health and welfare, western states have had to move quickly to understand and respond to non-urban areas with O_3 concentrations nearing the federal NAAQS, as well as the background and transported O_3 affecting existing nonattainment areas from beyond those areas' boundaries.

Rural areas with high concentrations of O_3 and low numbers of local sources likely responsible for elevated O_3 concentrations have brought a new focus on the analysis of transport, uncontrollable sources of O_3 precursors, and background O_3. More stringent O_3 NAAQS have also necessarily led to further analysis of background and transported O_3 affecting existing nonattainment areas. Other western planning needs such as identification of both controllable and uncontrollable sources contributing to O_3 transport, identification of O_3 exceptional events (EEs), and clarification of the application of planning mechanisms offered in the U.S. Clean Air Act (international transport §179B demonstrations and §182 Rural Transport Areas) all depend on accurately quantifying background O_3. Western states need detailed O_3 analyses focusing on the western United States to gain a better understanding of the origin of O_3 precursors, photochemical activity, and fate of transported O_3 with a level of confidence that will lead to the development and implementation of effective regulatory programs for the West.

The U.S. Environmental Protection Agency (EPA) defines U.S. background (USB) O_3 to be any O_3 formed from sources or processes other than U.S. manmade emissions of nitrogen oxides (NOx), volatile organic compounds (VOCs), methane (CH_4), and carbon monoxide (CO).[1] In the West, USB sources may include international transport of O_3 precursors, stratospheric intrusion, lightning, biogenic emissions, and wildfire. Along the West Coast, seasonal USB O_3 mean concentrations are in the range of 30–50 parts per billion (ppb).[2] Levels of USB O_3 in remote intermountain west high-altitude locations, including many intermountain national parks, significantly contribute to the overall O_3 concentrations measured.

Table 1 shows O_3 design values (ODV) at paired monitoring sites for the maximum daily 8-hr average (MDA8) value, the compliance statistic for the O_3 NAAQS. Note that for these paired nearby locations within each state, higher elevation sites have higher design values attributable to higher USB O_3. In each state, the lower elevation site is in a small urban or rural location, while the elevated site is more remote. The large USB O_3 signal relative to the compliance level of the O_3 NAAQS (0.070 parts per million, ppm) for rural and remote sites, which are typical of large areas of the West, complicates the task of western air regulatory agencies to meet federal air quality requirements, including attainment and maintenance of the O_3 NAAQS and issues with determination of O_3 transport into the United States and/or between states. The accurate identification and quantification of USB O_3, as well as a correct representation of atmospheric chemistry and transport, are necessary to determine what control measures for local sources will be effective in reducing ambient O_3. As discussed below, quantifying USB O_3 is challenging.

Characterizing Ozone for Air Quality Planning Decisions in the West

Primary tools used by states and EPA to manage air quality are the State Implementation Plans (SIPs)[3] or Federal Implementation Plans (FIPs). These documents are federally-enforceable plans developed by and/or for states that identify how the state will attain and/or maintain the air quality standards. A key component of each SIP is the maintenance of a network of regulatory O_3 monitors operated by the state that use standardized sampling methodologies, quality assurance, and siting requirements established by EPA, along with complementary monitors operated by other federal,

Table 1. Comparison of O_3 ODVs for adjacent sites with differences in elevations >1,000 m (2013–2015).[a]

State	Site	Coordinates	Meters ASL	O_3 Design Value (ppb)[b]
Oregon	Bend	44.02°N, 121.26°W	1,135	59
Oregon	Mt. Bachelor	43.98°N, 121.69°W	2,763	77
Wyoming	Carbon	41.78°N, 107.12°W	2,015	55
Wyoming	Centennia	41.36°N, 106.24°W	3,178	66

Notes:
a Data are from EPA Air Quality System (AQS) database (https://www.epa.gov/aqs) except for the non-regulatory Mt. Bachelor measurements, which are from the University of Washington data archive (https://digital.lib.washington.edu/Researchworks).
b The MDA8 values used in the ODV calculations are only the data acquired with start hours between 0700 and 2300 local standard time. The ODV is the three-year average of the 4th highest annual MDA8, calculated after approved EE data have been excluded from AQS. For all sites listed here, no EE days were identified or excluded from the ODV calculation. Note that EEs have not been formally evaluated for the Mt. Bachelor data, since it is not a regulatory monitor.

tribal, and local agencies. Knowledge of the sources contributing to the ambient levels on the highest O_3 days is important because controlling the domestic contribution to O_3 production affects the estimates of both the health benefits and the economic costs and benefits associated with achieving the NAAQS.[4] This knowledge is also important for SIP development because it helps states identify the most effective emission control strategies.

Quantifying USB O_3 requires a complicated mix of modeling and evaluation using observational data; however, missing pieces of scientific understanding of some sources of O_3 precursors such as wildfire, stratospheric intrusion, and international/interstate transport hinder the use of these data for air quality planning and affects the accuracy of results. Most O_3 monitoring in the United States is accomplished in urban areas or in those rural areas with significant influence from nearby, O_3 precursor sources such as oil and gas production areas in the Intermountain West. There are few monitors along the West Coast in remote locations that might be considered representative of the USB O_3 entering the western United States.

Air quality computer models require accurate emissions, comprehensive representation of physical and chemical processes in the atmosphere, and the ability to replicate plume dispersion to yield useful results. There are several modeling approaches that have been employed to quantify USB O_3, and each approach has strengths and weaknesses. The resolution of O_3 NAAQS compliance planning issues becomes difficult due to two major factors: (1) USB O_3 contributes substantially to monitored concentrations, quantification methodologies are lacking necessary analytical capabilities, and have substantial uncertainties; and (2) air regulators are able to evaluate and further control the relatively small fractions of controllable local precursors contributing to monitored O_3 levels in their plans to reduce O_3 levels. Figure 1 demonstrates this complexity with conceptual models for O_3 sources (a) in the United States and (b) at a single location.

The trend in the annual fourth highest daily average 8-hr O_3 concentration for 2000–2017 for nine urban U.S. locations—San Bernardino, Chicago, Atlanta, Boston, Albuquerque, Sacramento, Salt Lake City, Denver, and Reno—is presented

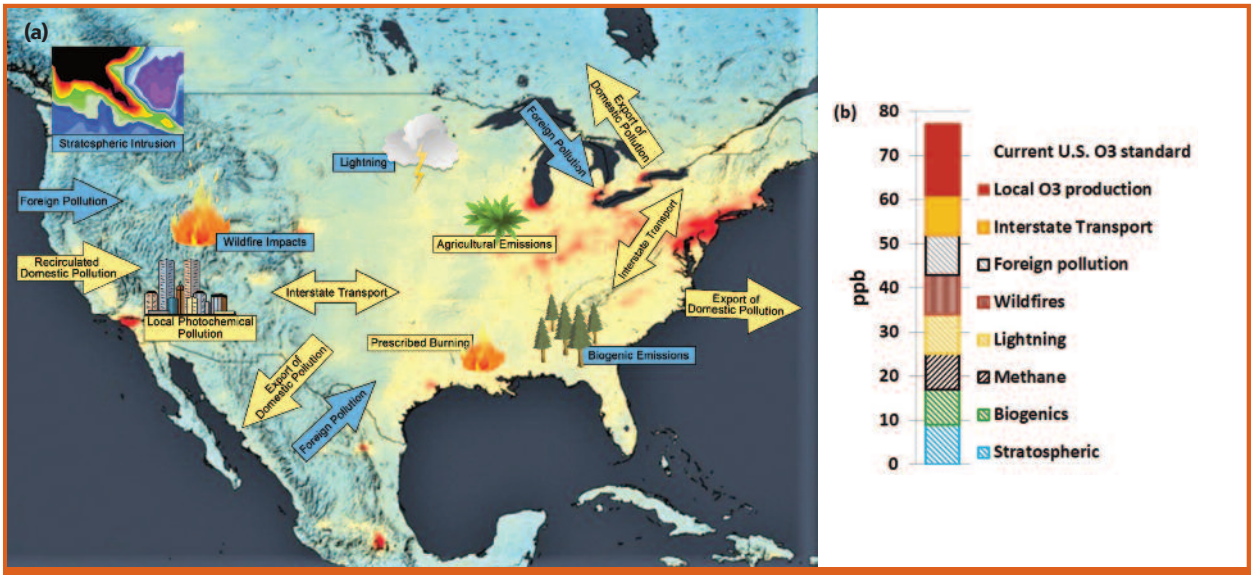

Figure 1. Conceptual models for O_3 sources (a) in the United States and (b) at a single location.

Notes:
(a) The U.S. O_3 sources shown with yellow boxes or arrows represent domestic/controllable anthropogenic sources. Sources shown with blue boxes or arrows represent USB/uncontrollable sources. Note that locations for each process are not specific to any one region. The base map shows satellite-observed tropospheric nitrogen dioxide (NO_2) column concentrations for 2014 from the Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite (*Credit*: NASA Goddard's Scientific Visualization Studio/T. Schindler). NO_2 column amounts are relative with red colors showing highest values, followed by yellow then blue. OMI NO_2 is a proxy to show local O_3 precursor emission sources.
(b) The bar chart shows a theoretical example of how both domestic anthropogenic and USB O_3 sources combine to produce elevated O_3 at a specific location on any given day. Each source varies daily and there are also nonlinear interactions between USB O_3 sources and domestic anthropogenic sources that can further add to O_3 formation (e.g., forest fires and urban emissions).[5]

in Figure 2. In each location, a single monitoring site with one of the highest ozone design values in that urban area was chosen. San Bernardino, Atlanta, Boston, Albuquerque, and Sacramento all show statistically significant downward trends in the fourth highest 8-hr ozone concentration whereas the non-coastal western cities, Salt Lake City, Denver, and Reno, plus Chicago show no significant trend since 2000. Overall, the significant reductions in the urban areas are generally consistent with the rural O_3 trends. The downward trends in fourth highest MDA8 O_3 concentrations are linked to significant reductions in emissions of O_3 precursors, while at the same time there can be important regional differences in such precursor emission trends (e.g., emissions related to oil and gas extraction in some parts of the western states) that can help explain some of the weaker trends. Three of the four locations with no significant trend are high elevation sites (Salt Lake City, Denver, and Reno). Trends in O_3 at these western sites might also be influenced by increasing wildfire activity.

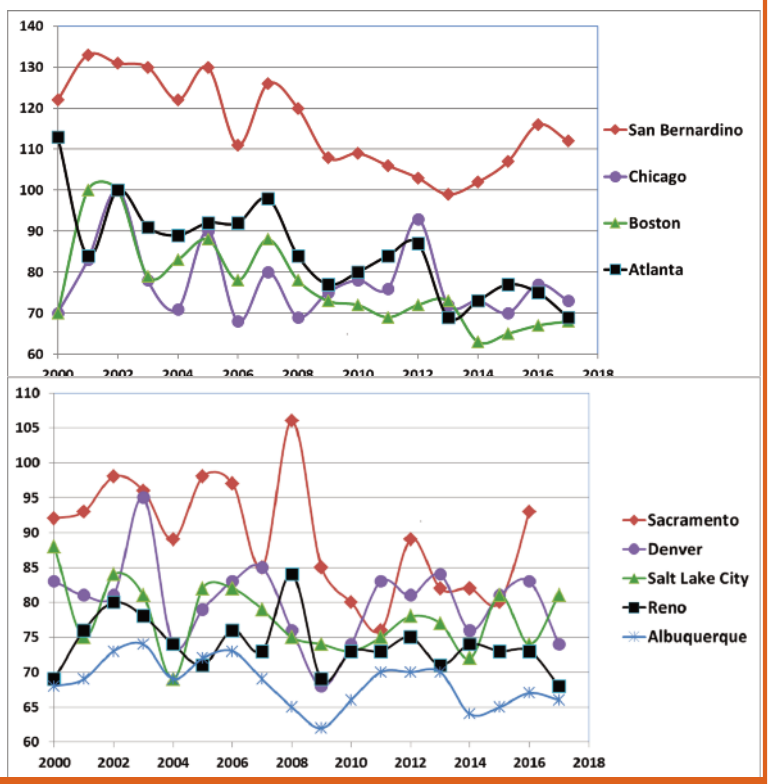

Figure 2. Annual fourth highest MDA8 O_3 (ppb) for one site in each urban area.

Note:
Data shown include any exceptional event days that may have been excluded from the ODV calculation.

Quantification of USB O_3 is essential for air quality management in general, and for state and local efforts to meet the NAAQS, in particular. This is especially true given the recent lowering of the O_3 NAAQS levels and the associated increasing relative importance of USB O3 as domestic precursor emissions decrease. Quantification of USB O_3 requires a chemical transport model (CTM), since it cannot be measured directly, but these models must be informed and evaluated using observations. Most estimates of USB O_3 have been made using regional CTMs such as the Community Multiscale Air Quality Modeling System (CMAQ)[6] and the Comprehensive Air Quality Model with Extensions (CAMx)[7] that are initialized using lateral boundary conditions derived from global models. The model approaches used to estimate USB O_3 have different merits, limitations, and best uses. Different methods of employing CTMs may be best suited (scientifically or computationally) to a specific policy or research question.

USB Ozone Influence on Regional Air Quality Modeling: A Western Case Study

SIPs and FIPs require models to accurately simulate O_3 sources so that the models can be used to examine emission control scenarios to demonstrate future attainment of the NAAQS. Presented here is a case study illustrating results of comparative regulatory applications of the regional modeling platforms. The regulatory analysis excludes identified exceptional days and focuses on the top 10 monitored O_3 days. While this case study compares only two models, it adds to the weight of evidence of the need for further western analyses, as it provides insights into the relationships between regional model estimates of USB O_3 and observations.

The EPA Transport Assessment[8] and the Western Air Quality Study[9] both independently performed model simulations of USB O_3 at 12-km resolution in Colorado for 2011. This is an ideal case study for USB O_3 relevant to state planning because the western states typically have high USB O_3 contributions, and because the Northern Colorado Front Range often experiences high O_3 levels that exceed the NAAQS. The modeling systems in both assessments used global simulations to provide high-time-resolution, varying boundary conditions; EPA used the GEOS-Chem modeling while WAQS used MOZARTv4. USB O_3 contributions were determined as the sum of boundary and natural sources tagged with tracers in the modeling systems, of O_3 from May 1 through Sept. 29. Simulation results were compared for contributions of local, regional, and USB

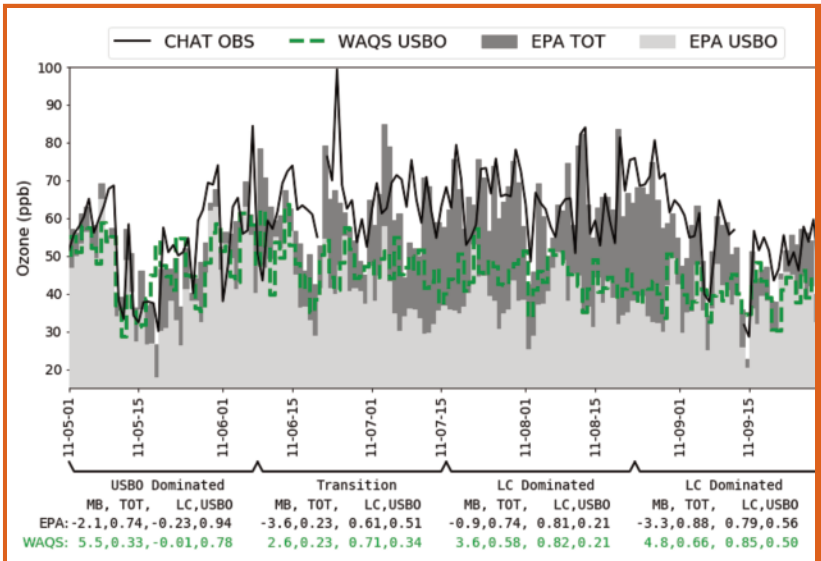

Figure 3. Observed and modeled MDA8 O with USB O from EPA model and WAQS for Chatfield. Observed O_3 (black lines), EPA model MDA8 O_3 (top of dark grey), EPA model USB O_3 (top of light grey), and WAQS USB O_3 (dashed green lines). For four simulation segments, the values below the axis give (for both models) the mean bias (MB), correlation (r) of total prediction with observations (TOT), correlation of local contribution (LC) with observations, and correlation of USB O_3 contribution with observations (USBO). DOI: https://doi.org/10.1525/elementa.309.f6

O_3 sources at a suburban monitor southwest of Denver (Chatfield) and at Rocky Mountain National Park.

EPA and WAQS 2011 modeling for Chatfield and Rocky Mountain National Park highlights similarities between the GEOS-Chem and the MOZARTv4 models, but also confirms the need to improve modeling of USB O_3. Jaffe et al.[10] provide correlations between observations and source contributions at Chatfield over the whole period are generally consistent with previous studies,[11-13] showing that:

1. as illustrated in Figure 1b and Figure 3, USB O_3 and natural/uncontrollable O_3 sources within the United States are significant fractions of total monitored O_3;
2. the monitored and predicted O_3 levels are most strongly correlated with the local contribution; and
3. boundary conditions are anti-correlated with the local contribution of O_3 sources.

Conclusions

Concentrations of O_3 in rural areas of the West originate from a mix of locally controllable and uncontrollable USB sources. Because of this and the fact that, historically, O_3 nonattainment planning policies have focused on resolution of urban O_3 exceedances, a greater emphasis on the identification and quantification of USB O_3 sources is also now necessary for effective regulatory decision-making. While O_3 modeling in the eastern United States has been accomplished through federally-funded efforts under the Ozone Transport Commission, no similar effort with federal funding have ever been initiated in the West. Western states have long commented that EPA should provide funding to help states better understand O_3 background, uncontrollable sources of O_3 precursors and transport in the West.

As a result of the EPA's extraordinary funding support in the East, eastern states have been able to develop a better understanding of the origin of O_3 precursors, O_3 formation, and the fate of O_3 with a level of confidence that helped with the development and implementation of meaningful and effective regulatory programs to improve air quality. The slim differences in the West between the seasonal mean USB O_3 level and the 2015 O_3 NAAQS alone drives a need for increased precision in model accuracy. Western states need detailed O_3 analyses focusing on the western United States to gain a better understanding of the origin of O_3 precursors, photochemical activity, and fate of transported O_3 with a level of confidence that will lead to the development and implementation of effective regulatory programs for the West. **em**

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Author's Note

The authors relied upon the Jaffe, et. al. paper cited next as the primary source for our article under the Creative Commons use policy. We express our sincere gratitude to Dr. Jaffe and his co-authors.

Jaffe, D.A.; Cooper, O.R.; Fiore, A.M.; Henderson, B.H.; Tonnesen, G.S.; Russell, A.G.; Henze, D.K.; Langford, A.O.; Lin, M.; Moore, T. Scientific assessment of background ozone over the U.S.: Implications for air quality management; *Elem. Sci. Anth.* **2018**, 6 (1):56; DOI: http://doi.org/10.1525/elementa.309.

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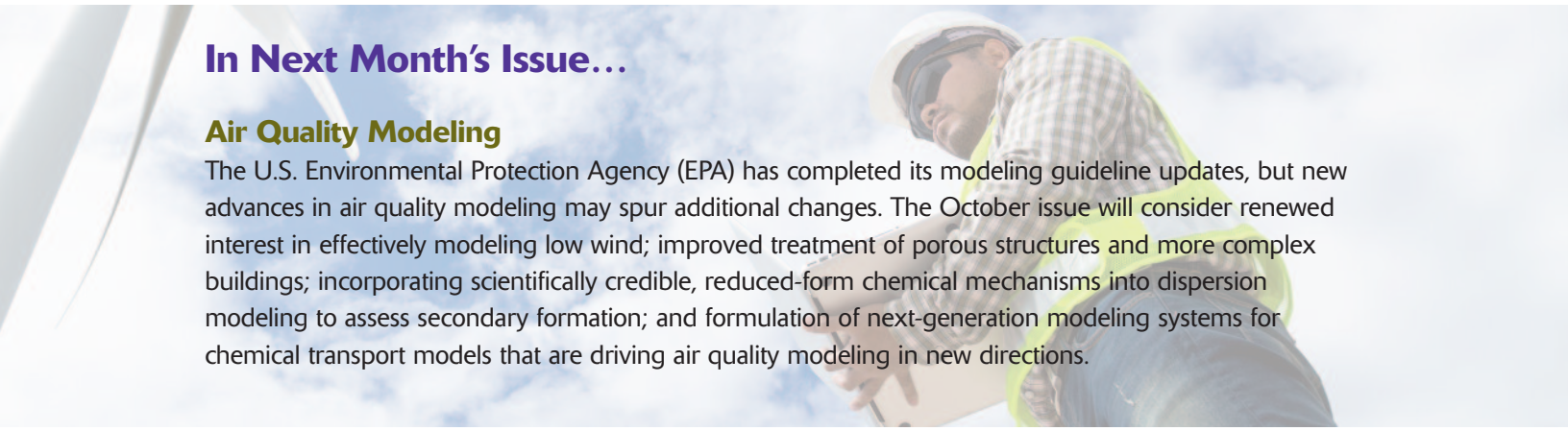

In Next Month's Issue…

Air Quality Modeling

The U.S. Environmental Protection Agency (EPA) has completed its modeling guideline updates, but new advances in air quality modeling may spur additional changes. The October issue will consider renewed interest in effectively modeling low wind; improved treatment of porous structures and more complex buildings; incorporating scientifically credible, reduced-form chemical mechanisms into dispersion modeling to assess secondary formation; and formulation of next-generation modeling systems for chemical transport models that are driving air quality modeling in new directions.